ARMY RESEARCH LABORATORY

Evaluation of an Infrared Camera for Use in a Gun-Launched Unmanned Aerial Vehicle

by Marshal A. Childers and John A. Condon

ARL-TR-3302 September 2004

NOTICES

Disclaimers

Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5069

ARL-TR-3302 **September 2004**

Evaluation of an Infrared Camera for Use in a Gun-Launched Unmanned Aerial Vehicle

Marshal A. Childers and John A. Condon
Weapons and Materials Research Directorate, ARL

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED (From - To)**
September 2004	Final	February 2004 to July 2004

4. TITLE AND SUBTITLE Evaluation of an Infrared Camera for Use in a Gun-Launched Unmanned Aerial Vehicle	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Marshal A. Childers and John A. Condon (both of ARL)	**5d. PROJECT NUMBER** 1L162618H80
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory Weapons and Materials Research Directorate Aberdeen Proving Ground, MD 21005-5069	**8. PERFORMING ORGANIZATION REPORT NUMBER** ARL-TR-3302
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

A commercially available infrared (IR) camera was evaluated for potential application on the silent operating aerial reconnaissance (SOAR) gun-launched unmanned aerial vehicle (GLUAV). The objective was to provide data to support an IR imaging camera capability for SOAR. Components of a candidate IR camera were subjected to high acceleration shock experiments to predict gun-launch survivability. The experimental results show that the camera in its off-the-shelf condition cannot survive the expected loads that are representative of a zone 4 120-mm mortar launch.

15. SUBJECT TERMS

infrared; reconnaissance; shock testing; SOAR; UAV

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
					Marshal A. Childers
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** (*Include area code*)
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL	20	410-306-0717

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Contents

List of Figures

Acknowledgments

The authors thank Mr. Melvin Ridgley (formerly of ARL) for his assistance in providing x-rays of the camera and lens assemblies. The authors thank Mr. Jamie King of Dynamic Sciences, Inc. (DSI) for his assistance with the application of glass beads to encapsulate the camera board assembly. Mr. Peter Kornik and Mr. Darin Murray of Janos Technology advised the authors about the component material properties and structural design of the lens assembly. The authors further thank Mr. Shawn Dirksen of Indigo Systems, Inc., for informing them about details of the camera design and for analyzing the mode of failure of the camera after experimentation (reference contract of support and procurement DAAD1703-03-P-0875).

INTENTIONALLY LEFT BLANK

1. Introduction

The gun-launched silent operating aerial reconnaissance (SOAR) vehicle is a small folding wing aerial vehicle that has potential to provide real-time reconnaissance, targeting, battle damage assessment, meteorological data, and a communication link (*1*). There is a need to extend the capabilities of SOAR to low light or night operational scenarios. Thermal imaging cameras are successfully used on larger unmanned aerial vehicles (UAV) such as Pointer (*2*). The objective of the work presented here was to determine the high-g survivability of a thermal imaging camera for use on SOAR. The U.S. Army's 120-mm M930/M983 illuminating mortar cartridge is the proposed delivery platform for the SOAR vehicle. In this delivery concept, the SOAR vehicle is contained within the mortar cartridge during mortar launch and is expelled from the cartridge during an in-flight expulsion event.

Omega[1] is a thermal imaging infrared (IR) camera that uses uncooled microbolometer[2] detectors and proprietary on-focal plane signal processing. Currently, Omega is the smallest commercially available IR camera. Further information about this camera is available on the manufacturer's web site[3]. The current size of the SOAR electronics cavity requires the use of an IR camera that is smaller and lighter than Omega and a custom external mirror design to provide an appropriate viewing angle.

To evaluate survivability of the camera, experiments were performed to simulate mortar launch of the SOAR vehicle. Given that the typical zone 4 launch acceleration for the selected mortar is approximately 10,000 g, a conservative launch acceleration of 15,000 g was chosen as the criterion for survivability of the camera. The approach used to determine the survivability of this camera in a gun launch environment was limited in that only one unit was evaluated because of its relatively high cost (approximately $10,000 for a quantity of one to five) and long lead time. The lens assembly and the camera were tested separately, but the shutter assembly was not tested. It is assumed that the camera can be re-programmed to prevent in-flight recalibration so that the shutter assembly can be eliminated. The work in this report does not consider the effect of the mortar expulsion event on the camera which imparts approximately 3,000 g in the direction opposite the launch direction.

The apparatus used to simulate the mortar launch acceleration was the MTS[4] IMPAC66 high velocity acceleration (HVA) shock test machine. The mechanism consists of a 33-lb high-

[1]On June 8, 2004, the name was changed from Omega to ThermoVision Micron.

[2]A microbolometer is a type of technology for thermal imaging. Microbolometers are thermoelectric in nature, which means when the detector senses IR energy, it reacts by changing resistance. The change is then measured by the "read-out" electronics to create a thermal image for viewing.

[3]http:www.indigosystems.com

[4]Not an acronym; MTS Systems Corporation, 14000 Technology Dr., Eden Prairie, MN 55344-2290.

strength forged aluminum table that is accelerated with bungee cords onto a 450-lb steel reaction mass (see figure 1). In order to obtain a shock pulse of desired maximum deceleration and duration, it is necessary to place a mitigating material (programmer) between the shock table and reaction base. This material has energy absorption characteristics, and typical programmers used for high-g (>1000-g) applications are constructed from felt or urethane materials. Detailed information about the use of this system for high-g and low-g applications was reported in references (*3*) and (*4*).

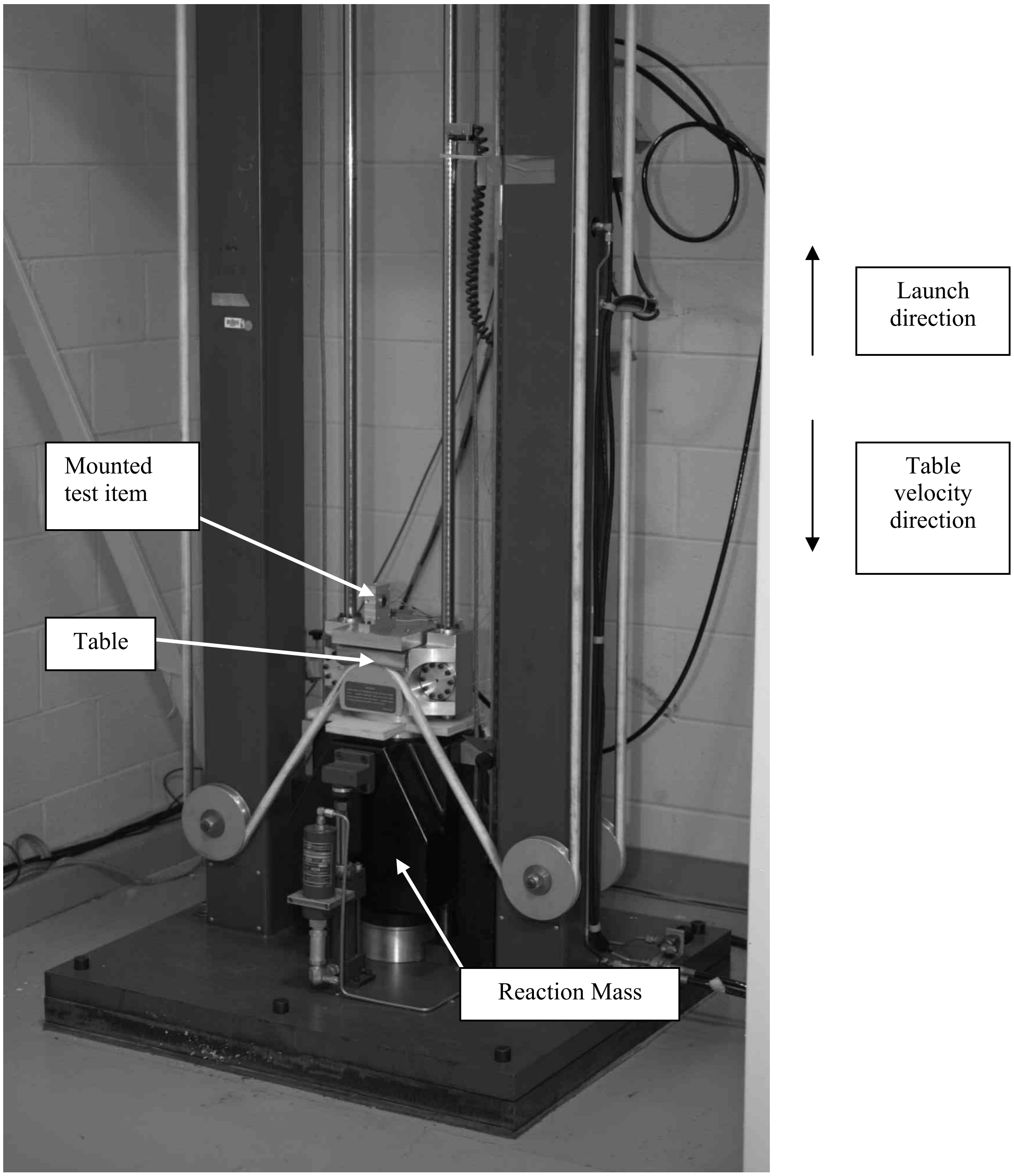

Figure 1. MTS IMPAC66 HVA shock test machine.

2. Lens Assembly Evaluation

The lens assembly consists of a barrel that contains the lens, barrel housing, and a mounting plate that connects the assembly to the camera body. The lens is machined from zinc selenide and is glued to the inside of the barrel. The barrel is held in the housing by friction, and a set screw enables manual focusing of the lens by means of a guide groove (see figure 2). An x-ray of the lens assembly is shown in figure 3.

Figure 2. Barrel.

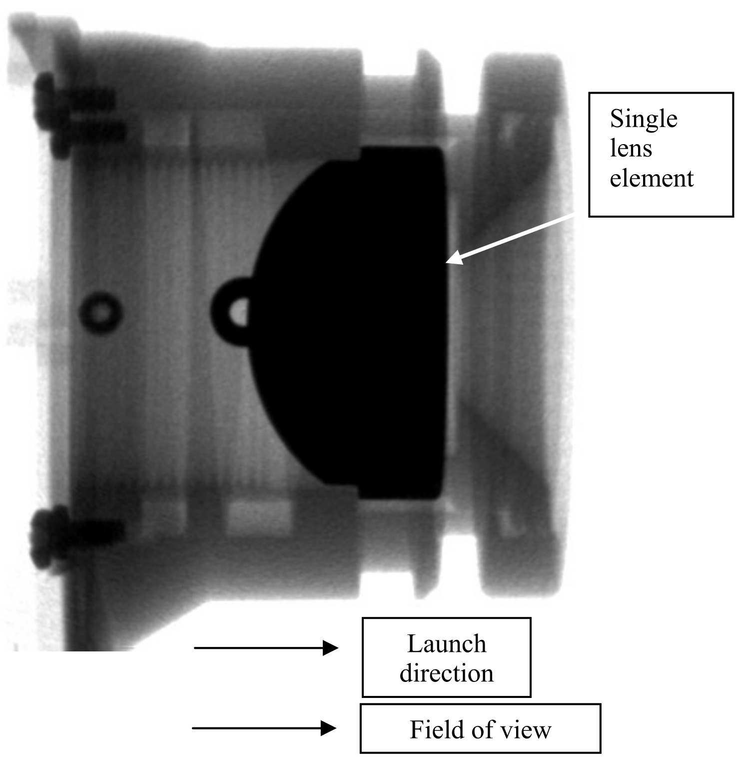

Figure 3. Pre-shock x-ray image of lens assembly.

The proposed camera orientation is such that the camera faces the forward direction along the SOAR vehicle thrust axis. The lens assembly was tested separately from the camera. To secure the lens assembly during the shock event, a fixture was designed to attach the lens assembly to the shock table by the four mounting holes in the lens assembly (see figure 4). The fixture was fabricated from 7075-T6 aluminum.

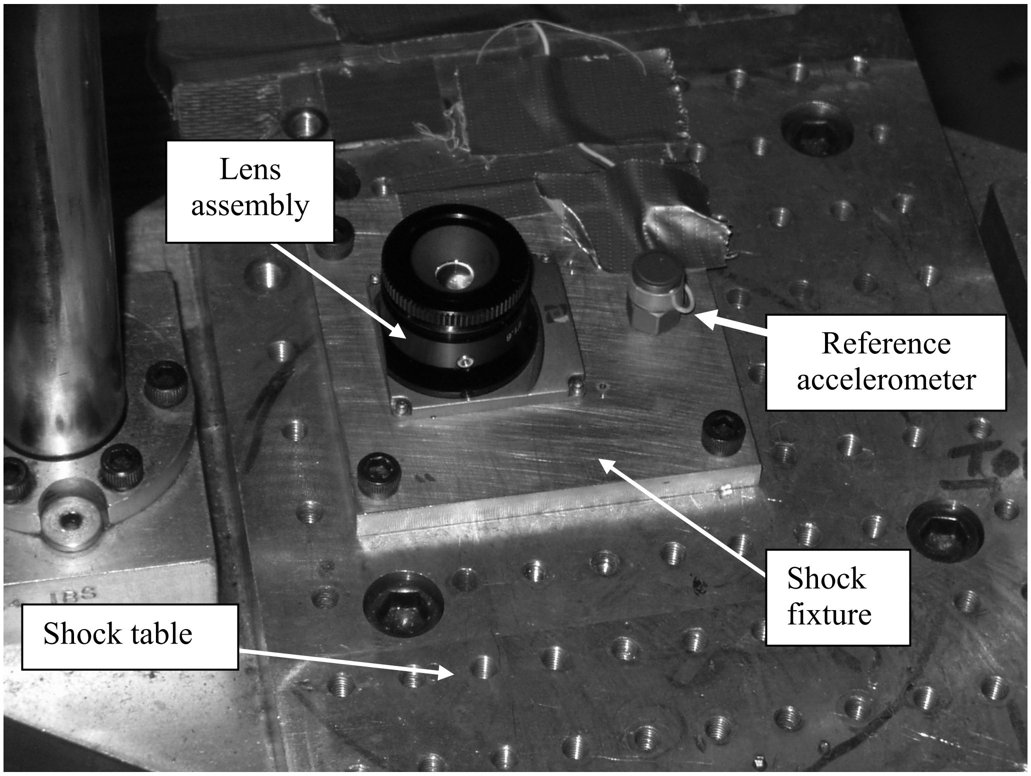

Figure 4. Lens assembly attached to shock test fixture.

Three shock events were incrementally applied to the same lens assembly with maximum shock levels of approximately 2000 g, 5000 g, and 11,000 g. A PCB[5] Piezotronics[6] model 350B02 reference accelerometer was attached to the shock fixture to measure the deceleration magnitude and duration of each shock event.

The shock pulse for the first shock is shown in figure 5. A 2300-g maximum deceleration of 60-microsecond (μs) duration was applied to the lens assembly. No damage to the lens assembly was sustained during this shock event, as verified by visual inspection and post-shock imaging upon camera reassembly.

The second shock event achieved a maximum deceleration of 5600 g with a 55-μs duration. No damage was sustained by the lens assembly during the second shock event.

---

[5]Not an acronym

[6]PCB Piezotronics, Inc., http://www.pcb.com

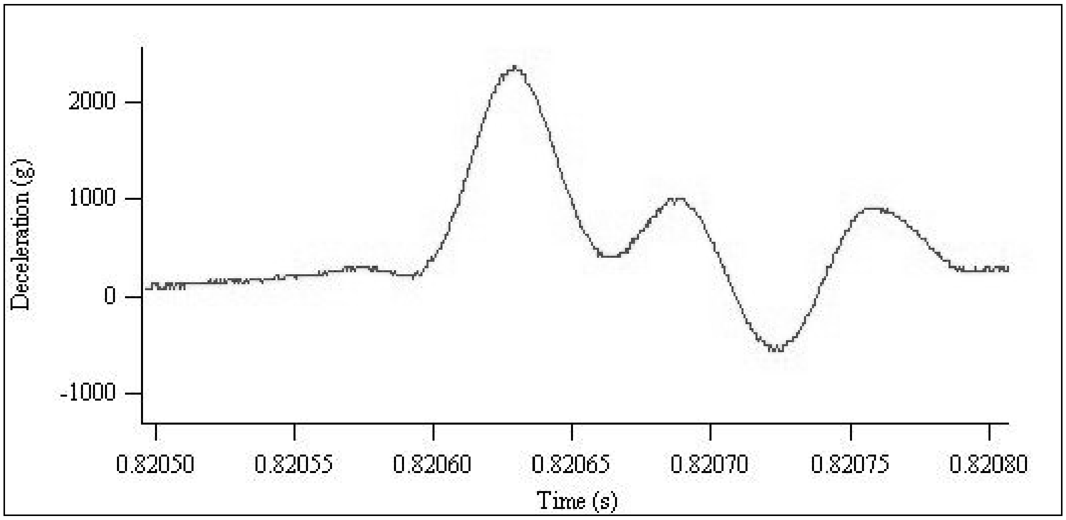

Figure 5. Pulse from first shock test event.

The third shock that was applied to the lens assembly achieved an 11,300-g maximum deceleration of 50-µs duration. Significant damage was sustained by the lens during this shock event. The lens fractured so that the unsupported back half of the lens dislodged from the portion that was glued to the barrel. The x-ray in figure 6 shows that the fracture initiated at the shoulder edge where the lens was supported by the barrel. The lens was nonfunctional as a result of the third shock event (see figures 7 and 8).

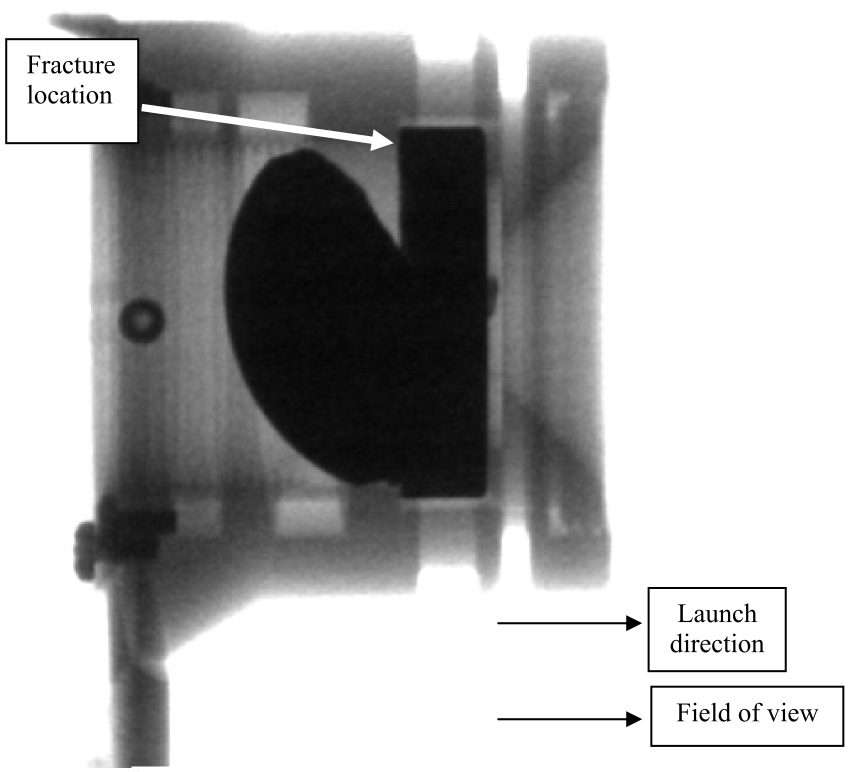

Figure 6. Post-shock x-ray image of lens assembly.

Figure 7. Pre-shock lens.

Figure 8. Lens fracture resulting from shock testing.

The cost of a replacement lens, as quoted by Indigo Systems Corporation, is $900.00. The lens manufacturer[7] claimed that by removing stress risers in the lens geometry and improving the method of supporting the lens, they could redesign the lens so that it could withstand a 15,000-g maximum acceleration shock event. The cost for a new lens design, as quoted by the lens manufacturer, was $2,200.00 for non-recurring engineering costs and $1,610.00 for five lenses ($6,393.00 for one lens).

[7]Janos Technology, 1068 Grafton Road, Townshend, Vermont 05353-9605.

3. Camera Evaluation

The Indigo Omega camera (see figure 9) is a long wavelength IR (7.5 to 13.5 microns) system that obtains thermal images via an uncooled microbolometer. The approximate camera dimensions are 1.35 inches high by 1.45 inches wide by 1.9 inches long, and the weight of the unit (including lens) is 120 grams. Figure 10 shows an x-ray of the camera and shows that the circuit boards are supported only at the edges. The system consists of two circuit boards that interconnect via flexible ribbon cables to permit folding of the boards into the orientation shown in the x-ray. Visual inspection of the structure revealed that the circuit boards were attached to the camera case by two 0-80[8] unified fine-thread series (UNF) screws and were supported on one side by a heat shield. To increase the shock survivability of the camera, glass spheres were used to support and encapsulate the electronics inside the camera body. Glass spheres were chosen to facilitate inspection after shock testing. (It is envisioned that a typical non-removable encapsulation material would be applied in a final production version.) The glass spheres, with a diameter of 270 microns, were vibrated into the camera case on a vibration table that is actuated by rotating imbalance. A clear acrylic box of the same dimensions as the camera case (see figure 11) was used to observe the glass bead encapsulation of the circuit boards. It was visually determined that the glass spheres thoroughly filled the spaces between the circuit boards and between the circuit components. The acrylic box was only used to qualify the encapsulation method; all testing was conducted with the actual camera case.

Figure 9. Indigo omega camera.

To verify that the glass spheres did not adversely affect the camera functionality, we performed video imaging before and after encapsulation. Figures 12 and 13 compare still photographs taken from the pre-encapsulation and post-encapsulation videos. The figure shows that there was no appreciable loss in the image quality as a result of glass sphere encapsulation.

[8] size 0, 80 turns per inch

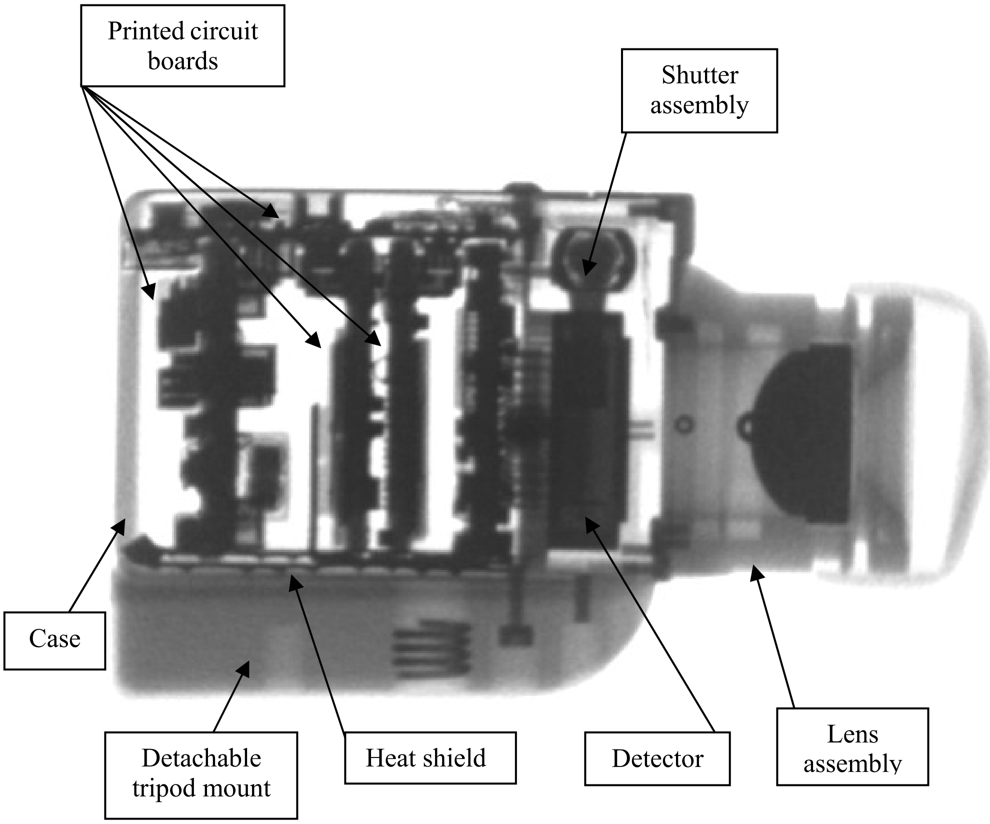

Figure 10. X-ray image of indigo omega camera.

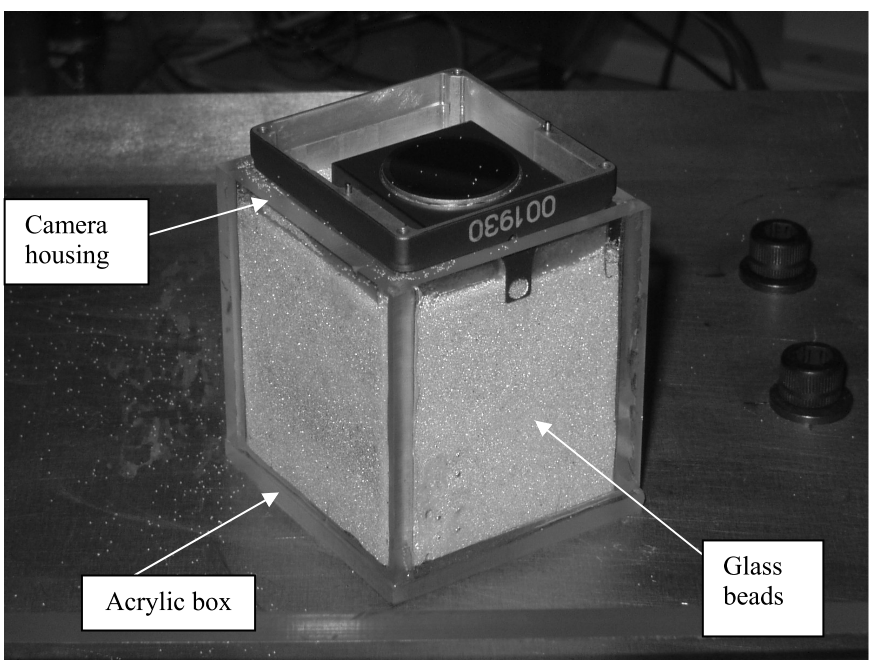

Figure 11. Glass bead encapsulation of camera board assembly.

Figure 12. Pre-encapsulation infrared video still image.

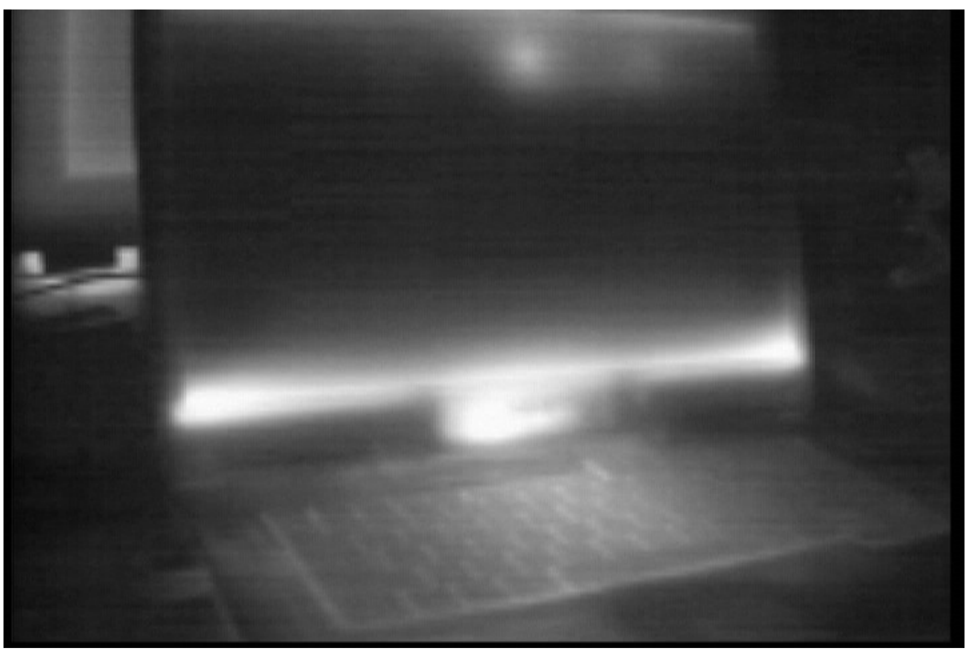

Figure 13. Post-encapsulation infrared video still image.

To secure the camera to the shock test system table, a fixture was designed and fabricated from 7075-T6 aluminum. The viewing axis of the camera was oriented parallel to the shock table deceleration axis with the lens facing the acceleration (launch) direction. Four 4-40 unified course-thread series (UNC) screws were used to attach the fixture to the shock table. A PCB Piezotronics model 350B02 reference accelerometer was attached directly to the shock table to measure the deceleration magnitude and duration of the shock event.

The objective of the shock experiments for the camera was to apply maximum deceleration values of 5000 g, 10,000 g, and 15,000 g incrementally in a series of three shock tests.

The first shock test performed on the camera achieved a 5000-g maximum deceleration of 72-μs duration. As a result of the first shock test, the camera was nonfunctional in that the system did not start during the post-shock evaluation. A visual inspection of the camera components did not reveal any defects in the camera components.

As a result of post-shock test evaluation performed by the manufacturer, the printed circuit boards were verified to be intact and functional. The evaluation suggested that the failure was attributable to a "short" in the gold-plated substrate, caused by slumping of the detector wire bonds. The manufacturer recommended that removal of the gold plate substrate will enable the use of shorter wire bonds. According to a study performed at the U.S. Army Research Laboratory (*5*), shortening the wire bond lengths should increase shock survivability.

The cost to replace the detector and calibrate the system, as quoted by the manufacturer, was $2,301.78.

4. Conclusion

The Omega camera, in commercial-off-the-shelf condition, is not capable of surviving in a typical gun launch environment. Changes in the sensor wire bond design are required to increase the potential for zone 4 mortar launch survivability. Shortening the wire bonds and encapsulating them in a shock-mitigating material should increase launch survivability. Some modification of either the camera or the SOAR vehicle may permit a soft launch (approximately 250 to 500 g) application of the Omega camera. If the SOAR vehicle electronics cavity were enlarged to accommodate the Omega camera or if the size of the Omega camera housing were reduced to fit the camera in the electronics cavity, the Omega camera would be a candidate for a soft launch, thermal imaging scenario.

5. Recommendation

To enable the use of a modified Omega camera in a zone 4 mortar launch scenario, it is recommended that the wire bonds in the sensor be "hardened" by the shortening of the bond length. Furthermore, the gold plate substrate should be removed to prevent "shorting" of the wires. To determine the shock survivability of a modified sensor, further shock experimentation is required. To determine the suitability of using the Omega camera in a soft launch environment, it is recommended to assess shock survivability of the camera by shock testing at low levels (approximately 250 to 500 g) of acceleration. To mount the camera inside the SOAR vehicle, it is recommended that the size of the camera housing be decreased or the diameter of the SOAR vehicle electronics cavity be increased.

6. References

1. Aerovironment Incorporated Design Development Center, *FQM-151A (Pointer) Hand-launched Unmanned Aerial Vehicle System*, Simi Valley CA, October 2002.

2. Miralles, C. T. *Gun-launched Unmanned Aerial Vehicle Flight Demonstration and Concept Validation*; ARL-CR-0515; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, March 2003.

3. Childers, M. A. *Evaluation of the IMPAC66 Shock Test Machine, Serial Number 118*; ARL-TR-2840; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, October 2002.

4. Garner, J. M. *Shock Test Machine User's Guide*; ARL-TN-23; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, September 1993.

5. Katulka, G.; Ridgley, M. *Test Results of Munitons Interconnects During Shock and Spin Experiments*; ARL-TR-2792; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, August 2002.

NO. OF COPIES	ORGANIZATION
*	ADMINISTRATOR DEFENSE TECHNICAL INFO CTR ATTN DTIC OCA 8725 JOHN J KINGMAN RD STE 0944 FT BELVOIR VA 22060-6218 *pdf file only
1	DIRECTOR US ARMY RSCH LABORATORY ATTN IMNE AD IM DR MAIL & REC MGMT 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	DIRECTOR US ARMY RSCH LABORATORY ATTN AMSRD ARL CI OK TECH LIB 2800 POWDER MILL RD ADELPHI MD 20783-1197
4	DIRECTOR US ARMY RSCH LABORATORY ATTN AMSRD ARL SE RL M DUBEY B PIEKARSKI AMSRD ARL SE RM AMSRD ARL SE SS LADAS 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	CDR US ARMY TACOM ARDEC ATTN AMSTA AR FSP M HOLLIS PICATINNY ARSENAL NJ 07806-5000
1	PROGRAM MGR ITTS STRICOM ATTN AMFTI EL D SCHNEIDER 12350 RESEARCH PKWY ORLANDO FL 32826-3276
1	US ARMY CECOM RDEC ATTN AMSEL RD NV AS UEA G KLAUBER 10221 BURBECK ROAD FORT BELVOIR VA 22060-5806
2	AEROVIRONMENT INC ATTN C MIRALLES 4685-3H INDUSTRIAL ST SIMI VALLEY CA 93063

ABERDEEN PROVING GROUND

NO. OF COPIES	ORGANIZATION
1	DIRECTOR US ARMY RSCH LABORATORY ATTN AMSRD ARL CI OK (TECH LIB) BLDG 4600
2	CDR USA AMSAA ATTN AMXSY EF AMXSY EV BLDG 392
1	US ARMY EVALUATION CMD ATTN USA CSTE EAC AZ R MIRABELLE BLDG 4120
2	CDR US ARMAMENT RD&E CTR ATTN AMSTA AR FST T J MATTS J WHITESIDE BLDG 120
1	CDR USA DTC ATTN CSTE DTC TTM J SCHNELL RYAN BLDG
3	DIR USARL ATTN AMSRD ARL WM J SMITH T ROSENBERGER H WALLACE BLDG 4600
1	DIR USARL ATTN AMSRD ARL WM B W CIEPIELLA BLDG 4600
23	DIR USARL ATTN AMSRD ARL WM BA T BROWN (2 CYS) F BRANDON T BROSSEAU M CHILDERS (5 CYS) J CONDON (2 CYS) B DAVIS T HARKINS D HEPNER K HUBBARD G KATULKA D LYON R MCGEE P MULLER M NAIR P PEREGINO A THOMPSON M WILSON BLDG 4600
2	DIR USARL ATTN AMSRD ARL WM BC P PLOSTINS J GARNER BLDG 390
2	DIR USARL ATTN AMSRD ARL WM BF H EDGE T HAUG BLDG 390
2	DIR USARL ATTN AMSRD ARL WM RP J BORNSTEIN C SHOEMAKER BLDG 1121